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Reevaluation of Design Loads for an Existing Avalanche Protection Gallery

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Introduction

- The verification of existing structures with current structural design codes is often difficult.
- The cost of retrofitting can be significant.

⇨ Are the required investments proportionate?

⇨ Is it possible to accept a lower reliability level?

The decision should be made based on risk and efficiency considerations!

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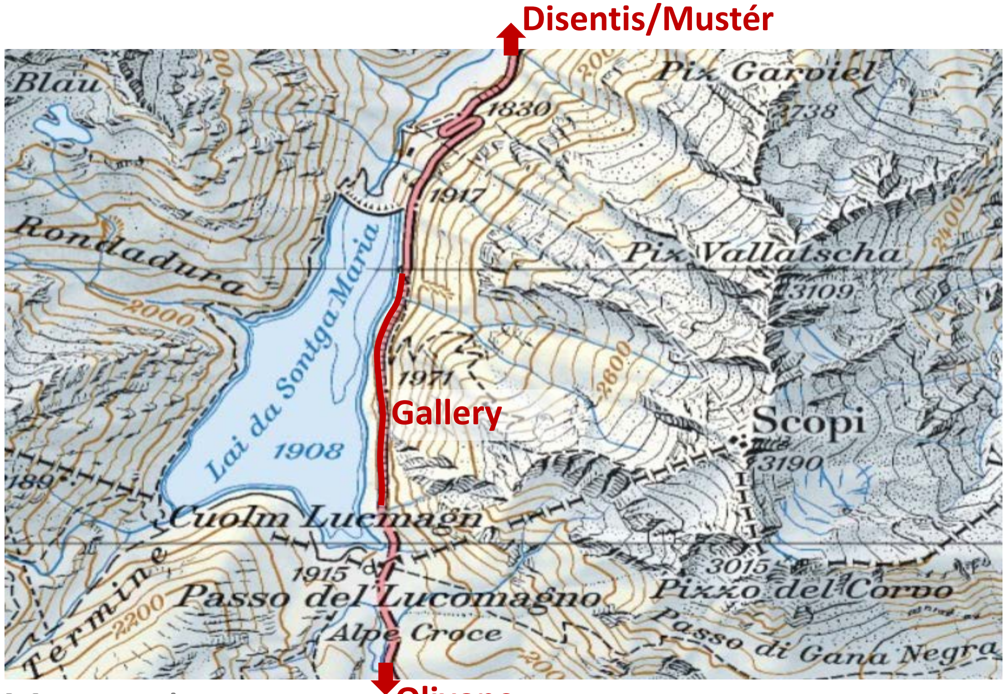
Application to an existing avalanche gallery

- Located in the Swiss Alps (GR)
- Built in the 1960's, 2km long
- Many avalanches, no damages
- Reassessment with new design loads based on ASTRA 12007
- Very high retrofitting costs!



Map: swisstopo

Source: TBA Graubünden

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Risk-based design based on SIA 269 / JCSS PMC

Efficiency of safety measure $E = \Delta R / C_S$	Failure consequences $\rho = C_F / C_B$		
	Minor $\rho < 2$	Moderate $2 < \rho < 5$	Large $5 < \rho < 10$
Small $E < 0.5$	$\beta_t = 3.1$ $P_f \approx 10^{-3}$	$\beta_t = 3.3$ $P_f \approx 5 \cdot 10^{-4}$	$\beta_t = 3.7$ $P_f \approx 10^{-4}$
Normal $0.5 \leq E \leq 2.0$	$\beta_t = 3.7$ $P_f \approx 10^{-4}$	$\beta_t = 4.2$ $P_f \approx 10^{-5}$	$\beta_t = 4.4$ $P_f \approx 5 \cdot 10^{-6}$
Large $E > 2.0$	$\beta_t = 4.2$ $P_f \approx 10^{-5}$	$\beta_t = 4.4$ $P_f \approx 5 \cdot 10^{-6}$	$\beta_t = 4.7$ $P_f \approx 10^{-6}$

Gallery example

- Minor consequences of failure
- Small efficiency of safety measure

⇨ **Annual target reliabilities based on optimisation**

Deriving design values from the target reliability

General formula:

$$X_d = F_X^{-1}\left(\Phi\left(\alpha_X \beta_t\right)\right)$$

Distribution of X FORM sensitivity

⇨ Required: Probabilistic model for the random variable X

⇨ Difficult for avalanche loads: Expert judgement is often the only information available

Source: TBA Graubünden

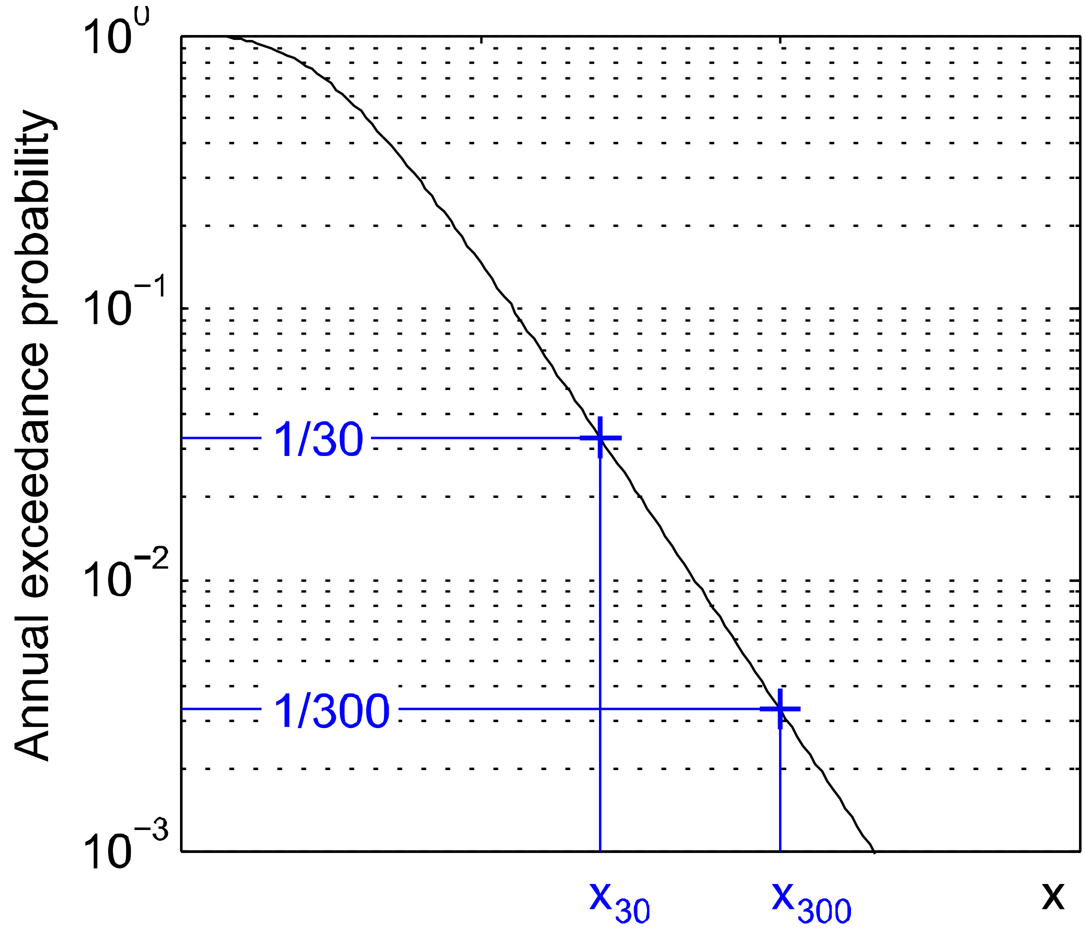
Probabilistic modelling of avalanche loads

Standard approach: Expert estimates for scenarios with predefined return periods

⇨ Exceedance probability [1/a]:

$$P\left(X > x_{T_i}\right) = 1/T_i$$

⇨ “Fit” probability distribution to several scenarios



Probabilistic modelling of avalanche loads

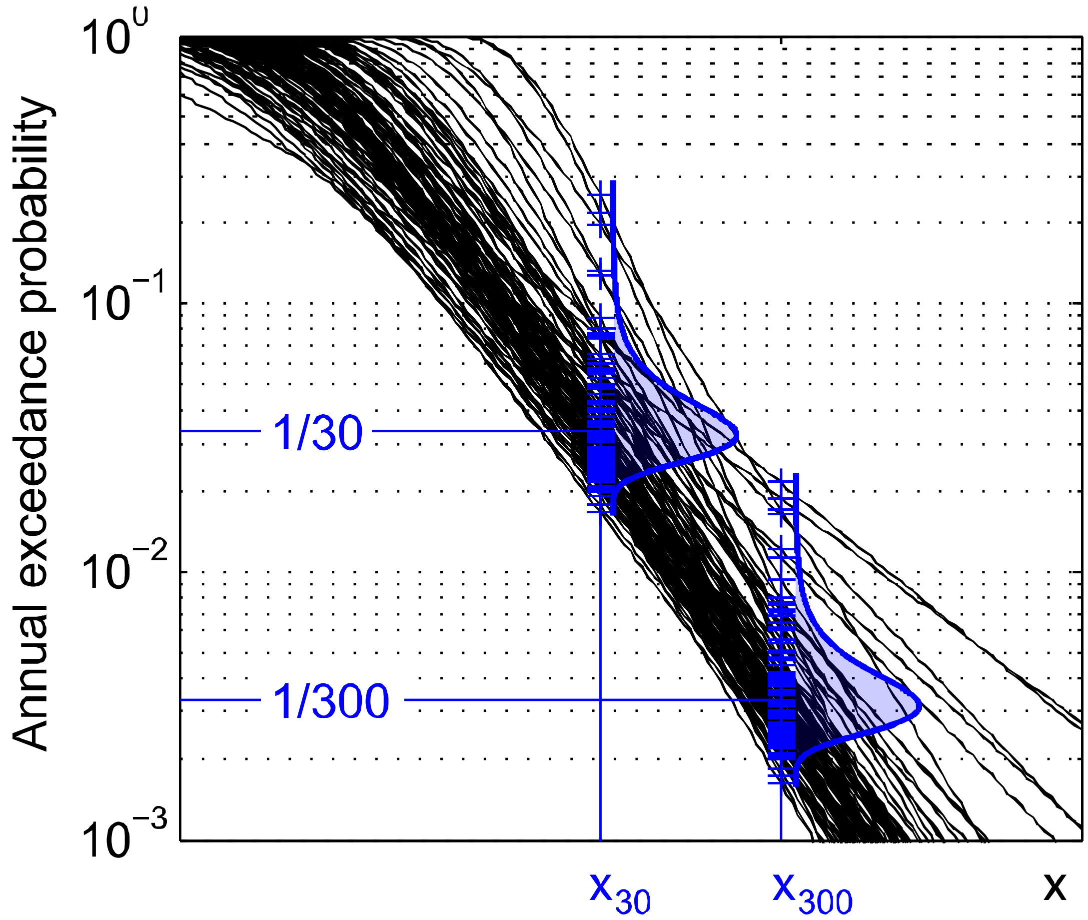
Standard approach: Expert estimates for scenarios with predefined return periods

⇨ Exceedance probability [1/a]:

$$P\left(X > x_{T_i}\right) = 1/T_i$$

⇨ “Fit” probability distribution to several scenarios

⇨ Quantify the uncertainty of the scenario estimates



Results for the avalanche protection gallery

- The new design loads were used for a structural reassessment.
- Assessment for $\beta_t = 3.1$ (low efficiency of safety measure) to decide which parts of the gallery have to be retrofitted.

⇨ Only around 30% of the 2km gallery have to be strengthened.

- Design values for $\beta_t = 4.2$ (high efficiency of safety measure) for the planning of retrofitting works.

⇨ The retrofitting works are planned with higher design loads than those derived from a standard, deterministic assessment.

⇨ More efficient resource allocation than in standard approach.

Conclusions

- The target reliabilities presented in SIA 269 / JCSS PMC allow to consider cost efficiency in a standard deterministic design.
- The approach requires probabilistic models for the considered load / resistance variables.
- Loads due to natural hazards (e.g. avalanches) can be modelled based on expert estimates for several scenarios.
- The application to existing structures leads to a more targeted investment of limited resources.

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